THE UNIVERSITY OF ALBERTA

THE POTASSIUM STATUS OF SOME ALBERTA SOILS

A THESIS

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ABSTRACT

The potassium values of approximately 3,000 soil samples submitted to the Agricultural Soil and Feed Testing Laboratory during the period 1959 to 1961 were plotted on a map of Alberta. It was observed that soils from the Brown, Dark Brown, and Thin Black zones generally had greater potassium contents than those from the Black, Transition, and Grey Wooded zones. In order to study some aspects of this observation, samples were collected for analyses from the Airdrie, Angus Ridge, Falun, and Uncas soil series which were situated in the Thin Black, Black, Transition, and Grey Wooded zones, respectively. An attempt was made to keep differences in factors such as texture, drainage, and parent material to a minimum.

Potassium extracted by 1 N NH_4Ac from the 0 to 6-inch depth showed that the Airdrie series contained approximately twice the amount of potassium than that of the other soils. The average values for the Airdrie, Angus Ridge, Falun, and Uncas series were 1.0, 0.4, 0.6, and 0.5 m.e. per 100 grams, respectively. Acid extractable potassium as determined by the boiling 1 N HNO_3 method gave 3.2, 1.7, 2.0, and 1.6 m.e. per 100 grams, respectively, for the above soils. The trend was similar to an estimate of the more soluble non-exchangeable potassium determined by five repeated extractions with boiling 1 N HNO_3.

Analyses of alfalfa grown on the Airdrie series compared to that grown on the Angus Ridge series show that

the potassium contents were 3.9 and 2.5 per cent, respectively. The higher soil potassium content of the Airdrie soil appears to favor luxury consumption. Mineralogical analyses of the Airdrie series suggest greater quantities of potassium bearing clay minerals than in the other soils. This may partially explain the higher potassium content of the Airdrie series as compared to the other soils.

It is suggested that the Airdrie series has undergone less weathering and consequently less leaching than the other soils, thereby soluble, exchangeable, and acid extractable forms have not been lost as readily through leaching.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Potassium is one of the six elements of the soil required in relatively large quantities by plants. The use of potassium fertilizers is not a generally accepted practice by farmers in Alberta. The agricultural soils of Alberta have been considered to contain adequate supplies of potassium for crop production (4, 5) and consequently very little study has been made on this major plant nutrient. The reasons that responses to potassium fertilizer have not been obtained are probably twofold: (i) the supply of available potassium was originally high and it may take a number of years of cropping for a serious depletion to appear, and (ii) even though the potassium in certain soils may have been insufficient for optimum yields, production has been controlled by a lack of nitrogen, phosphorus, and moisture. With an increased use of nitrogen and phosphate fertilizer in recent years, crop yields have been correspondingly increased and potassium may become a factor limiting crop production on certain soils.

Limited fertilizer tests in the past have generally shown little or no response to added potassium; thus, no further need for study was felt justified. Recent fertilizer tests, however, have indicated a number of yield responses to added potassium particularly on the Black, Transition, and Grey Wooded soils of west central Alberta (1, 2, 3). Upon close inspection of certain fertilizer trials conducted by personnel at the University of Alberta and at the Lethbridge Research Station it was observed that applications of potassium

to soils of the Dark Brown and Thin Black zones have somewhat decreased yields (1, 2, 3). Soil samples submitted by farmers to the Agricultural Soil and Feed Testing Laboratory show relatively higher quantities of "available" potassium for these latter soil zones than for soils from the Black and Grey Wooded zones. For instance, soils of the Dark Brown and Thin Black zones generally test 200 to 400 pounds per acre of available potassium as compared with 50 to 200 pounds per acre on the Black and Grey Wooded soils. These tests were made using the Spurway extracting solution (0.025 N HAc).

High exchangeable potassium has been associated elsewhere with yield decreases (9, 25, 62, 67) as a result of potassium antagonisms with other plant nutrients such as nitrogen, magnesium, and boron. Since little information of the potassium status of Alberta soils is presently available, some basic studies are prerequisite to problems such as potassium antagonisms.

The objectives of this study are as follows:

1. To investigate and characterize certain Alberta soils with respect to the exchangeable and non-exchangeable forms of potassium.
2. To determine the rate of release of potassium by these soils.
3. To determine the relationships among the different chemical methods of evaluating potassium release by soils.
4. To determine relative quantities of the 10-11 Å clay mineral content of these soils.

REVIEW OF LITERATURE

Forms of Soil Potassium

On the basis of total analysis, potassium is one of the most abundant of the nutrient elements present in mineral soils. Amounts as great as 40,000 to 60,000 pounds of K_2O per acre-furrow-slice are not uncommon (15). The quantity of potassium, which is held in an easily exchangeable form however, is very small. Most of this element is held rigidly as part of the potassium-bearing primary and clay minerals. The potassium nutrition of plants may be limited, in many instances, by the rate at which the potassium held in these forms is released to readily available forms (39).

It is believed by many soil researchers (47, 63, 66) that an equilibrium exists among various forms of potassium in the soil. The forms found in the soil may be divided into three categories on the basis of availability; i.e., (i) readily available consisting of exchangeable and water soluble potassium, (ii) slowly available which includes the non-exchangeable and some fixed potassium, and (iii) the relatively unavailable form found in the feldspars and micas of the soil (15). The readily available potassium constitutes only about 1 or 2 per cent of the total soil potassium. The water-soluble and exchangeable forms are believed to be in a dynamic equilibrium. From a practical standpoint, this equilibrium is quite important. The soil solution form makes up about 10 per cent of the readily available potassium and may be subject to leaching.

The absorption of this form by plants results in a movement of the equilibrium; thus, some exchangeable potassium is made water-soluble until the equilibrium is again restored. The addition of potassium fertilizers would greatly increase the water-soluble potassium content; hence, this reaction would be reversed. Direct absorption by plants from the colloidal surfaces is also thought to occur (42). Potassium in the exchangeable form can also become "fixed" between the lattice structures of some clay minerals (15, 16, 18, 29, 53, 64).

The "slowly available" form of potassium referred to above includes that portion of potassium not directly exchangeable by chemical methods as well as "fixed" potassium. This form is, however, in equilibrium with the readily available forms and acts as a reservoir of slowly available potassium (15). This equilibrium may be expressed in the form of an equation:

$$\text{Non-exchangeable K} \rightleftharpoons \text{Exchangeable K} \rightleftharpoons \text{Soil Solution K.}$$

According to Garman (18), Hissink proposed the basic concept of an equilibrium between the different forms. Wiklander (64) suggests the rate of reaction between the exchangeable and soil solution forms is very rapid in both directions while the fixation reaction, i.e. exchangeable to non-exchangeable, is relatively rapid. The rate of the reverse of this latter reaction is, however, very slow. The application of soluble potassium fertilizers causes the above equilibrium to shift to the left with a large portion of the soluble potassium attaching to the soil colloids and some of the exchangeable becoming "fixed"

or non-exchangeable. This renders some potassium temporarily unavailable but not subject to leaching. This potassium may be slowly released later to growing plants.

Garman (18) proposed a modified equilibrium equation since he felt the simple equation is only useful when there is agreement on the definitions of terms. Exchangeable potassium is defined as the quantity removed by a definite extractant of specific concentration and soil:extractant ratio and he states this is not truly a characteristic entity of the soil. Garman proposed the following:

$$\begin{array}{ccccc} & & \text{Exchangeable K} & & \\ & & | & & \\ \text{Water-soluble K} & \rightleftharpoons & \text{Adsorbed K} & \rightleftharpoons & \text{Structural K} \\ & & | & & \\ & & \text{Non-exchangeable K.} & & \end{array}$$

The reason for placing exchangeable and non-exchangeable outside the equilibrium is that these forms are defined by some specific chemical method of extraction. Furthermore, "adsorbed" potassium is not synonymous with exchangeable potassium; likewise, non-exchangeable potassium may include some strongly adsorbed potassium. He defines "adsorbed" potassium as that fraction held electrostatically by excess negative charges on the surface of clay minerals and organic matter. The differences in location, accessibility, and bonding energies explain why an extraction such as with neutral ammonium acetate does not remove all adsorbed potassium. "Structural K" in his equation is that portion of soil potassium which is combined in the crystal structures of both primary and secondary minerals.

Mortland (42), however, feels these categories for the forms of soil potassium are derived empirically, in that each is frequently defined according to a particular procedure used for its analysis. Various procedures for any one form of potassium will therefore give a variety of values. Mortland suggests that to describe the equilibrium existing in the soil by the use of mass action equations would be an over-simplification of the actual processes. Mortland's recent work on the study of potassium release and fixation seems to indicate potassium in the soil has a dynamic character or nature and his experimental evidence showed that potassium release and fixation can occur simultaneously in a system containing a heterogenous group of 2:1 minerals not in equilibrium with each other. He reports that the rate of potassium fixation was found to be inversely proportional to the initial potassium content of the clay minerals.

Water-soluble and exchangeable potassium are considered to be readily available to plants either directly by contact exchange or indirectly by the equilibrium:

$$\text{Soluble K} \rightleftharpoons \text{Exchangeable K.}$$

Elements essential to the life of plants may be classified as nutritive or regulatory. Potassium functions as a regulatory element. Potassium is essential for many of the life processes of plants such as carbohydrate production, photosynthesis, hydrolytic activity of enzymes, and carbohydrate transfer. Unlike nitrogen, phosphorus, calcium, and magnesium, the potassium ion does not enter into permanent organic

combinations in plants, but apparently exists as soluble inorganic and organic salts. Thus, it is rather difficult to assign specific roles within closely related physiological processes (31).

Legume hays have the highest potassium content of any group of agricultural crops. Alfalfa, sweet clover, and vetch values range between 1.75 and 2.0 per cent potassium (41). Good yields of alfalfa and sweet clover require from 100 to 130 pounds of potassium per acre. Lawton (31) found an increase of 50 per cent in the potassium content of legume-grass hay by top-dressing with 150 pounds K_2O per acre.

Potassium Fixation

If potassium added to a soil is so firmly bound that it is not immediately replaceable with neutral salts, it is said to be fixed (48). Fixed potassium is assumed to be bound chiefly between the basal planes of the micaceous minerals in the hexagonal oxygen cavities normally occupied by the potassium ion as a lattice constituent in the micas (64). Through leaching and weathering, some of the lattice potassium ions migrate out of these positions and are replaced by other ions. This substitution of potassium by other ions causes the mineral to be somewhat "degraded" in so far as the potassium content is concerned. The lattice may expand somewhat if water (or rather H_3O^+) has replaced the potassium. Fixation causes a decrease in the exchange capacity approximately equivalent to the amount fixed (64).

Kardos (29) reports the clay size fraction of the soil is primarily responsible for potassium fixation; however, the kinds and amounts of clay minerals present largely determine the degree of fixation. The exact mechanism or mechanisms that govern potassium fixation and release are not clearly understood; however, several soil conditions are known to influence the amount of fixation (15). Some of these factors are: (i) the nature of the soil colloids, (ii) wetting and drying, (iii) freezing and thawing, and (iv) the presence of other cations.

It is presumed that fixation proceeds from the surface and edges to the centre of the clay particles and that ion diffusion is a rate determining factor. Consequently, fixation should be relatively rapid at the beginning and then become slower the nearer the equilibrium point. Wiklander (64) showed that in a silt loam 70 per cent of the total fixation of one milliequivalent per 100 grams occurred during the first two hours. At the end of 60 days, 97 per cent of the total had been fixed.

Schuffelen and van der Marel (53) summarize some of the recent concepts of the fixation mechanism: (a) the fixation can be caused by the entrapping of potassium ions between the lattice layers of vermiculite and "open" illite, (b) by substitution of potassium on valence places from substitued Si^{4+} by Al^{3+}, (c) by the locking up of the potassium ions in small holes or canals of zeolite, permutites, and amorphous material, and (d) by the restoration of the potassium ions in superficially weathered minerals such as illite and the feldspars.

They report that the opening and closing of illite and vermiculite is demonstrated by X-ray diagrams and differential-thermal analysis. Montmorillonitic clays, however, are not believed to be responsible for cationic fixation (29). Chemical fixation of potassium by organic matter has not been observed (53). Fixed potassium is thought by some (44, 64) to be a natural transition or "way station" between the exchangeable potassium and the lattice potassium. These researchers state that it is impossible to distinquish between lattice and fixed potassium.

Fixed potassium is available to plants only if "defixation" or "release" has occurred (64). This availability of fixed potassium to plants depends largely upon the type of fixation mechanism which has occurred in the soil. Potassium release from non-exchangeable forms by cropping has been carried out by numerous researchers (12, 46, 49, 53, 58). From many experiments listed by Schuffelen and van der Marel (53), they concluded that fixed potassium is not totally inaccessible to the plant. Therefore, it would seem desirable to have some measure of a soil's ability to release non-exchangeable potassium. Chemical methods for extracting this form of potassium will be discussed later.

Potassium fixation may even be beneficial as it tends to temporarily retain applied potassium in an immobile state and thus prevent losses to leaching (15, 53). However, in orchards on fine textured soils, which fix potassium strongly, applied potassium is fixed near the surface and the roots of trees in the subsoil receive very little potassium (53).

Potassium in Soil Minerals

The major portion of the total potassium in most mineral soils is found in the potassium-bearing primary and clay minerals in a non-exchangeable form (53). Primary minerals upon weathering will release potassium (15). Grim (20) states that the non-clay minerals are generally very abundant in soils; however, their particle size usually exceeds two microns. Among these are the potassium bearing feldspars such as orthoclase and microcline; general formula: $KAlSi_3O_8$. Andreatta (6) states that probably orthoclase is the most important primary mineral in regards to the release of potassium to soil during weathering. Reitemeier (48), however, indicates that the two potassium feldspars contribute little to growing plants as compared with the micas, biotite, and muscovite. MacKenzie (32) states that the feldspars occur in small amounts, thus the quantity of potassium released is not of any great consequence.

Predominant among the minerals which are known to release potassium upon weathering are the micaceous minerals such as biotite and muscovite. There exists considerable confusion in the classification of the potassium bearing minerals and clay minerals and this has arisen generally from the definition of illite. The term illite was proposed earlier by Grim (20) as a general term, not as a specific clay mineral name, for the mica-like clay minerals. Thus, the muscovite crystallization is classified as the dioctahedral type and biotite crystallization as the trioctahedral type.

More recently Grim (20) and MacKenzie (32) suggested that a continuous series exists between the micas and the clay mineral vermiculite characterized by a decrease in potassium content and an increase in hydrion H_3O^+ content. Grim also suggested that typical illite has less substitution of Al^{3+} for Si^{4+} in the tetrahedral layer than mica and therefore requires less potassium to satisfy the negative charge. The term illite now tends to be used in rather a restricted sense to include only micas having approximately the same composition as described by Grim (20) with a K_2O content of about 6 to 8 per cent. The term hydrous mica according to MacKenzie is rather broader in significance and includes the various forms from the micas muscovite and biotite to the corresponding dioctahedral and trioctahedral forms of vermiculite and montmorillonite. Illite was proposed as the intermediate between hydromuscovite containing 8 to 9 per cent K_2O and Al-andreattite being the hydrous mica member with a greater H_3O^+ content and a K_2O content of 4 to 6 per cent (32). This latter form of hydrous mica has been called "degraded illite" (32).

Warshaw and Roy (61) indicate that under controlled humidity micas give a sharp 10 Å peak, whereas illite, hydromuscovite, and other members of this group give a broad band of 10 to 11 Å peaks.

The fixation and release of potassium is intimately associated with the type of colloid present in the soil. It

has been shown by Mortland et al. (43) that biotite may release potassium to plants much more readily than illite or muscovite. Vermiculite, a weathering product of biotite, can fix large quantities of potassium; however, this is more readily available to plant growth than when fixed by illite, biotite, muscovite, or bentonite (43). These workers indicate that the release of potassium by electrodialysis showed the presence initially of an easily extractable form of potassium. However, once this had been removed the muscovite gave only a very slow release of potassium compared to the more rapid release by biotite. Schuffelen and van der Marel (53) concluded that common mica minerals like muscovite, biotite, and the potassium feldspars do not fix potassium. Illite is a clay mineral common to many soils and is generally found in the coarse clay fraction, i.e. size ranges from 0.1 micron to 2.0 microns (15, 20). Rouse and Bertramson (51) suggested that the ability of a soil to release potassium to plants is correlated with the illite content of the soil.

The release of potassium in soils by the illite or more general "hydrous mica" group has been complicated by numerous factors which tend to obscure the relative importance of these clay minerals (48). The identification, estimation, and knowledge of their behavior in soils remain unsatisfactory. This results from a variety of causes such as (i) diffuse X-ray diffraction spectra, (ii) differences in basal spacings and

water contents, (iii) dissimilarity of the micas of soils and of geological deposits, (iv) occurrence in mixed layer minerals, (v) confusion with small particles of unaltered and degraded micas, and (vi) inadequate knowledge as to the mode of formation (48).

The release of potassium in considerable quantities in the exchangeable form by illite following drying has been reported (16). Mortland et al. (43) observed that illite released potassium less readily than biotite and that potassium released by illite resulted in no significant alteration of the X-ray diffraction pattern.

Upon reviewing the literature, it is somewhat confusing to find that illite can fix potassium. However, it appears that this confusion arises when the term illite is used for the broader group of "hydrous micas" rather than for a more specific clay mineral generally accepted as the intermediate form between muscovite and/or biotite and vermiculite. The fixation of potassium by illite has been widely reported (20, 57, 65, 66). Grim (20), however, points out that most illite found in soils which are undergoing leaching is somewhat "degraded", i.e., it is potassium deficient in that leaching has removed some potassium ions from positions between the layers. He states that upon the addition of potassium by weathering of other minerals or potassium fertilizers, the potassium ions go back into these normal positions and the illite is rebuilt. Wiklander (65) has shown that the amount of fixation in illite-type material

varies with the cations already adsorbed. Fixation was found to be relatively high for materials having calcium and hydrogen occupying some of the exchange sites and low for those having hydrogen and ammonium occupying some of the exchange sites. Stanford (57) has shown that the presence of hydrogen, ferric, and aluminum ions tend to block the fixation by illite.

Methods of Extracting Soil Potassium

Numerous chemical and biological methods have been tested which appear to have given a fair measure of potassium availability from the "exchangeable" and "non-exchangeable" forms of soil potassium. As a result of the equilibrium which is believed to exist in the soil, investigators agree that the quantities of potassium extracted cannot be categorized except that a certain amount can be removed with a specific extractant under a given set of conditions (18). For example, exchangeable potassium has been defined as that quantity removed with a definite extractant of specific concentration and soil:extractant ratio (18). The use of 1 N NH_4Ac has been considered by some workers to be the "standard" for extracting exchangeable potassium (27, 34). Merwin and Peech (34) found that the level of potassium increased rapidly following replacement with hydrogen or calcium but did not with ammonium acetate replacement. Since ammonium ions undergo equilibrium fixation in the highly charged interlayer spaces of clay

minerals in the same manner as does potassium, the release of non-exchangeable potassium to exchangeable form is retarded during ammonium acetate extraction.

Several workers have found that the exchangeable potassium values have given a high degree of correlation with plant response to added potassium in the greenhouse (38, 46) while others found a high degree of correlation between exchangeable potassium values and plant uptake in the greenhouse (12, 35, 55, 58). Hogg (24) in New Zealand found good correlations between exchangeable potassium and plant response on soils from the North Island but not for soils from the South Island. Others have found poor correlations between plant response and exchangeable potassium content (22, 51). Reitemeier (48) states that the initial level of exchangeable potassium is not an accurate index of the reserve supplying power of a soil unless it represents the equilibrium level of the soil. He feels that the recent tendency to regard exchangeable and available potassium as synonymous is rather subject to some doubt. The following are probable explanations for poor correlations between exchangeable potassium values and plant response: (i) the inability of plants to completely remove exchangeable potassium, (ii) the usual inclusion of soil solution potassium with exchangeable potassium, (iii) the release and fixation of potassium by the primary and clay minerals, and (iv) the specific differences among plants to use exchangeable and

non-exchangeable forms. Exchangeable potassium has been found to be a satisfactory estimation of available potassium when the exchangeable values are relatively high and plants utilize primarily exchangeable potassium. However, when exchangeable potassium is low, poor correlations are obtained since plants will largely extract non-exchangeable forms.

Hunter and Pratt (26) state that a measure of only one form of soil potassium cannot by itself serve as sufficient criteria for assessing the plant-available-potassium of all soils. Therefore, since it is known that plants obtain varying amounts of potassium from non-exchangeable forms, it seems desirable that the extent of a soil's ability to supply potassium from these forms be measured by some chemical means.

The extraction of non-exchangeable potassium has been accomplished using several procedures including electrodialysis, extraction with strong acids, exchange resins, and continuous greenhouse cropping. Potassium removed by prolonged crop growth has been used rather widely as an index of the more readily available non-exchangeable fraction. Of the foregoing, probably the most commonly used rapid method for the estimation of non-exchangeable or reserve supplying power of soils is that of extraction by strong acids either with or without the prior removal of exchangeable cations (17, 21, 47, 49, 51, 66). The extraction of potassium from the soil with boiling 1 N HNO_3 outlined by

Pratt and Morse (47) has been used extensively. The correlations of the total amount of potassium extracted by boiling 1 N HNO_3 with plant uptake and with plant response have been variable. Pope and Cheney (46) found a high degree of correlation between the total amount of potassium extracted with HNO_3 and the amount extracted by 10 successive croppings of Ladino clover in the greenhouse. They found that the amount of potassium released from non-exchangeable forms, i.e. total potassium removed by HNO_3 less exchangeable potassium, was also highly correlated with the amount released during greenhouse cropping. Semb and Uhlen (54) found a good correlation between crop yields and the potassium levels using the HNO_3 method. Others (24, 38, 58), however, have found varying correlations using boiling HNO_3 and potassium response and uptake.

Electrodialysis has been used as a method of extracting available quantities of nutrients. These studies indicated that carrying out the extraction for one or several days removed quantities of potassium only slightly in excess of the exchangeable amount (48). Reitemeier et al. (49) and Ayers et al. (10) used electrodialysis for periods up to 90 days for extraction of non-exchangeable potassium. During the period of from 1 to 4 days a quantity equal to the exchangeable fraction was removed which was then followed by a continuously decreasing rate for 10 to 20 days and then virtually a constant rate of release for a substantial period of time. Reitemeier et al. (49) found a high degree of

correlation for the amount released by this method with that removed by Ladino clover cropping and other extraction methods.

The electrodialysis and nitric acid extraction procedures are similar methods in that the soil is hydrogen saturated during extraction. The decomposition of some of the minerals as a consequence of this acidity is usually visible and it is presumed that much of the potassium is liberated as a result of crystal structure breakdown (48). The correlation between potassium extracted by cropping and acid methods does appear to be much poorer for soils of low supplying power because strong acids tend to extract appreciable amounts of non-exchangeable potassium from soils which yield only negligible amounts to plants.

Exchange resins for measuring plant available potassium have been used by some workers. MacLean (37) found that amounts of non-exchangeable potassium extracted from soils was significantly correlated with amounts removed by plants.

A disadvantage in using electrodialysis or resin extraction for routine laboratory analysis is the long extraction periods of a week to a month or more. A rapid procedure is needed which gives reproducible results and above all provides a fairly accurate indication of the potassium supply available to plants.

A review of the literature reveals that most workers have utilized a single extraction technique and very few have

dealt with the rate of release of potassium. Garman (18) points out that since the release of potassium is a continuously equilibrating system, few investigations have been undertaken to develop methods which demonstrate this character. A continuous percolation or leaching method was proposed in 1957 by Matthews and Smith (40) and Garman (18). The percolation procedure, however, was first outlined by Matthews in a doctorate thesis under the direction of M. Peech at Cornell University in 1952. Matthews and Smith and Garman found that this method for extracting exchangeable and non-exchangeable potassium significantly correlated with plant uptake in the greenhouse. The rate and amount of release differed for different soils and it was suggested by Matthews and Smith that the rate of release is a soil type characteristic and not a function of management or fertilization. Garman found by plotting cumulative amounts of potassium removed by continuous leaching, a similar group of curves with specific characteristics for each great soil group was obtained.

MacLean (37) has recently used the percolation procedure proposed by Garman and found a highly significant correlation coefficient relating the amounts of potassium removed and plant uptake. McEwen and Matthews (33) found a highly significant correlation between the clay content of 59 Ontario soils and the amounts of potassium released during percolation and during cropping in the greenhouse. MacLean _et al._ (36) found a similar relationship between clay content and non-exchangeable potassium extracted by 1 N HNO_3.

A repeated extraction of non-exchangeable potassium using boiling 1 N HNO_3 was first described by Haylock (23). This researcher felt that a single digestion with 1 N HNO_3 extracts only a portion of the potassium soluble in this reagent and that further digestions extract potassium at a rate characteristic of each soil. The amount of potassium extracted by 1 N HNO_3 is affected by cations such as potassium, ammonium, and calcium on the exchange complex. Thus, Haylock proposed that a homionic substrate be extracted by removing exchangeable potassium by soaking with 0.1 N HNO_3 and filtering before the first extraction. The non-removal of exchangeable potassium before extraction with 1 N HNO_3 may depress the amount of non-exchangeable potassium extracted by up to 0.3 m.e. per 100 grams of soil.

Haylock found there was considerable variation in the amount of potassium soluble in 1 N HNO_3. For all soils used in his study, he found that the first extraction removed more potassium than any other with an approximately constant rate being extracted following the third extraction. Haylock interpreted the data as two forms of potassium being extracted, one of limited solubility released at a constant rate and the other, a highly soluble form, very largely released in the first extraction. He found that the uptake of non-exchangeable potassium by Italian ryegrass cropped for 15 months to be very close to one-third of the soluble form of non-exchangeable potassium. When the soils were extracted following cropping, a reduction in the soluble form was found but no change was observed in the form of limited solubility.

MATERIALS AND METHODS

Field Experiments

A total of 12 sites were located on 6 soil series with the assistance of personnel of the Canada Department of Agriculture Soil Survey. The sites were located in the Thin Black, Black, Transition, and Grey Wooded soil zones of Alberta. The locations of the sites and the classification of the soils, according to the 1960 Canadian Classification adopted by the National Soil Survey Committee, are given in Table I. The locations of the sites with respect to soil zone are shown in Figure 1. The soils represented a wide range of soil potassium values as obtained by the Spurway extraction method used in the Alberta Soil and Feed Testing Laboratory. It is known by the work of others (55) that fine textured soils generally have higher potassium contents than coarse textured soils. Consequently, in this study an effort was made to choose soils of similar texture thereby eliminating a variable. It was reasoned that by using this procedure it would be ascertained whether soils series of similar texture from the various soil zones have different potassium status. The soils were medium in texture, have glacial till as their parent material and were well drained. Alfalfa was being grown in the fields in which the sites were located, the stands varying in age from 1 to 4 or 5 years. The soils have been described in considerable detail elsewhere (13, 14) and only brief descriptions need be given here.

TABLE I. THE LOCATION OF SOIL SAMPLING AND FERTILIZER TEST SITES AND CLASSIFICATION OF THE SOILS.

Site No.*	Co-operator	Land Description	Soil Order	Sub-group	Soil Series
1.	Church	SE 1-26-29-4	Chernozemic	Orthic Black	Airdrie
2.	Jones	NE 17-26-28-4	Chernozemic	Orthic Black	Airdrie
3.	Boyack	SE 29-26-26-4	Chernozemic	Orthic Black	Airdrie
4.	Maga	SW 10-39-28-4	Chernozemic	Eluviated Black	Cygnet
5.	Atkinson	NW 8-41-26-4	Chernozemic	Gleyed Black	Ponoka
6.	Wiesener	NE 17-49-25-4	Chernozemic	Eluviated Black	Angus Ridge
7.	Ripple	SW 33-54-21-4	Chernozemic	Eluviated Black	Angus Ridge
8.	Adam	SE 34-54-21-4	Chernozemic	Eluviated Black	Angus Ridge
9.	Mauschmeyer	NW 21-55-20-4	Chernozemic	Dark Grey	Falun
10.	Holmlund	NE 2-46-27-4	Chernozemic	Dark Grey	Falun
11.	Hughes	NE 33-50-23-4	Podzolic	Dark Grey Wooded	Uncas
12.	Williams	SE 4-51-21-4	Podzolic	Dark Grey Wooded	Uncas

* See Figure 1 for location with respect to the soil zones.

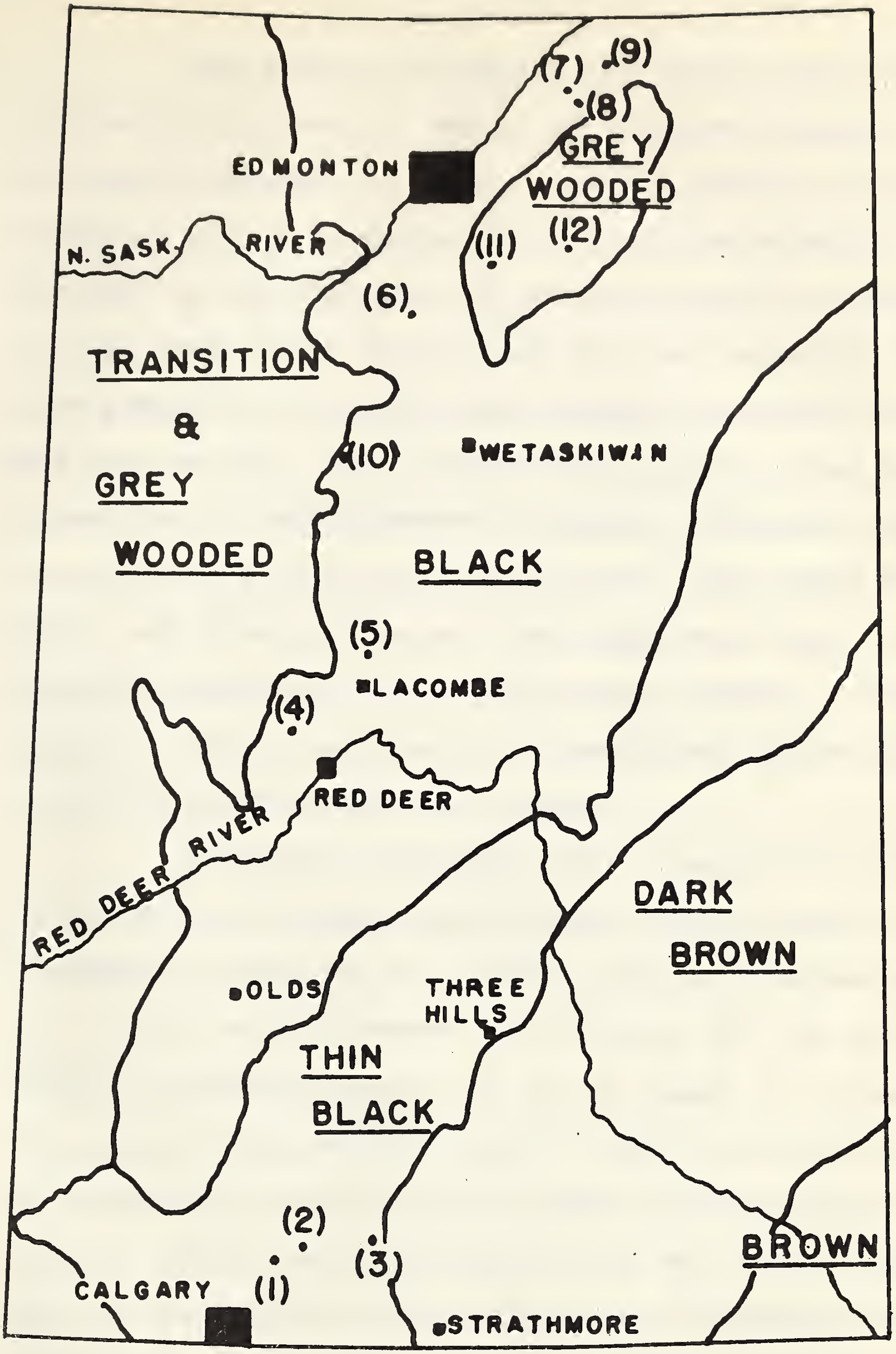

Figure 1. Map of Central Alberta showing the location of fertilizer and soil sampling sites (see Table I for key to site numbers).

The Airdrie and Cygnet soil series were developed on glacial till that is mainly of Paskapoo formation origin. The parent material is brown in color, contains sandstone erratics, and has a medium to high calcium carbonate content. The soil at the Atkinson site was developed on a sandy loam to clay loam parent material of alluvial-lacustrine deposition over glacial till. The parent material is usually low in lime and salt content. The profile was slightly gleyed and was classified as Ponoka Meadow.[1] However, throughout this study it is referred to as the Ponoka series. The Angus Ridge, Falun, and Uncas series were developed on glacial till of Edmonton formation origin. The parent material is brown to greyish brown in color and of a sandy clay texture with a low to medium calcium carbonate content.

Fertilizer treatments were placed on all sites except those of Hughes and Williams, sites 11 and 12. Fifteen treatments consisting of: (a) five levels of potassium at 0, 30, 60, 90, and 120 pounds K_2O per acre; (b) the same five levels in combination with 20 and 40 pounds of nitrogen and phosphorus, respectively; and (c) the five levels of potassium in combination with 40 and 80 pounds of nitrogen and phosphorus, respectively. Sulphur at the rate of 12 pounds per acre in the form of sodium sulphate was broadcast over the entire plot area. The treatments were replicated six times in a randomized block design. The plots measured 3 1/2 feet by 20 feet. One harvest was taken between June 15 and 23, and

[1] Personal communication with A. A. Kjearsgaard.

another between August 14 and 23. Green weights were recorded in the field and samples taken for moisture analysis in order to convert yields to oven dry weight basis. Plant samples for potassium analysis were collected during the second harvest. In order to ensure that all plants were at the same physiological stage of growth, only those just commencing to bloom were sampled. Terminals measuring five to six inches in length were sampled at random in each plot until approximately 100 to 125 grams of green weight material was collected. This gave approximately 25 grams of dry weight material.

Soil samples were collected with a "Bull" soil coring machine using a 1 1/4 inch tube during the first week of August, 1961. The major horizons were sampled with separations made on the basis of differences in structure, texture, and color. The samples were brought into the laboratory, air dried, passed through a 2 mm. sieve, and stored in glass screw-top containers until needed for analysis.

Chemical Analyses

The pH values were measured with a Beckman Model H-2 glass electrode pH meter using the saturated paste method of the United States Salinity Laboratory (60). Exchangeable calcium, magnesium, and potassium were extracted from the air dry soil samples with neutral ammonium acetate as outlined by Atkinson et al. (8). The cation exchange capacity was determined by the extraction of adsorbed ammonia with normal sodium chloride solution and distillation of the extract according to the magnesium oxide method for ammoniacal

nitrogen (7). Exchangeable calcium and magnesium were determined using the ethylenediaminetetracetic acid method as outlined in U.S.D.A. Handbook 60 (60). Exchangeable potassium was determined in the ammonium acetate extract with the Beckman Model DU flame spectrophotometer.

Chemical Methods for Determining Potassium Release

Potassium extracted by boiling 1 N HNO_3 was determined by placing 2.5 grams of soil in a 125 ml. Erlenmeyer flask, previously graduated to contain 100 ml., and adding 25 ml. of 1 N HNO_3. The suspension was mixed and placed on a hot plate, quickly brought to boiling and boiled for exactly 10 minutes. The flasks were then cooled to room temperature by placing them in a cold water bath until the solutions reached room temperature, and then diluted to 100 ml. with distilled water. The suspension was mixed well, allowed to stand for 10 minutes, and filtered through Whatman No. 50 filter paper. The potassium content of the extract was determined using a flame photometer. This method is similar to that of Greweling and Peech (17) except the ratio of soil to acid was 1 gm. to 10 ml. Rouse and Bertramson (51) found that a soil: acid ratio of 1 gm. to 10 ml. with a boiling time of 10 minutes proved to be best.

The Spurway extraction procedure (56) for estimating available potassium has been used for some time in the Agricultural Soil and Feed Testing Laboratory at the University

of Alberta. Five grams of soil were placed in 25 ml. of 0.025 N HAc extracting solution, shaken for 2 minutes, and filtered immediately. The potassium in the extract was determined with the flame photometer.

Repeated extractions with boiling 1 N HNO_3 has been proposed by Haylock (23) as a measure of the rate of release of non-exchangeable potassium. The method was recently revised by MacLean (37). A 5-gram sample of soil was soaked overnight in 50 ml. of 0.1 N HNO_3. The suspension was filtered through Whatman No. 50 filter paper in a Buchner funnel using a petroleum jelly seal to prevent loss of soil. The sample was leached with 5 additional 10 ml. portions of the acid. The sample and filter paper were then transferred to a 250 ml. electrolytic beaker, 50 ml. of 1 N HNO_3 were added with stirring, brought to a rapid boil on a hot plate, and allowed to boil for exactly 10 minutes at a reduced temperature sufficient to maintain boiling. The suspension was cooled and made up to 100 ml. with distilled water; the beakers were previously graduated to contain 100 ml. The suspension was centrifuged in the beakers for approximately 10 minutes at 1,200 r.p.m. The supernatant liquid was then decanted into 4-ounce glass bottles for storage until flame photometer analysis of the extract. The procedure of boiling, centrifuging, and decanting was repeated 5 times.

Potassium analyses of plant tissue were carried out by dry ashing for 2 hours at 500°C samples which had previously been ground on a Christie and Norris mill with

a one millimeter sieve. The residue was dissolved in 10 ml. of 1 N HNO_3 and made up to 250 ml. with 0.1 N HNO_3. Potassium was determined in the extract with the flame photometer.

All potassium determinations were performed with the Beckman Model DU Flame Spectrophotometer using the following instrument settings: wave-length 769 $m\mu$., red sensitive phototube, load resistor - 3, slit width 0.30 mm., acetylene 2.5 p.s.i., oxygen 9.0 p.s.i. Standard potassium solutions of 0, 0.5, 1.0, and 1.5 m.e. per litre were prepared in ammonium acetate. A "radiation" buffer containing 25 m.e. calcium, 50 m.e. magnesium, and 40 m.e. sodium per litre was used with the standard solutions and soil extracts. The foregoing standard solution and radiation buffer were used for the determination of potassium in the acetic acid and nitric acid extractions following the determination of their suitability by recovering added potassium.

Mechanical analyses were performed on all samples using the modified pipette method of Toogood and Peters (59). The fine clay content was determined by evaporating an aliquot separated from the other clay fraction by centrifugation (11). An estimate of organic matter content in the Aa and Ah horizons was made by determining the nitrogen content by the macro-Kjeldahl method (8). The ammonia was distilled into 4 per cent boric acid solution.

Mineralogical Analyses

The identification of the clay minerals in the coarse and fine clay fractions were made using X-ray diffraction techniques. The X-ray unit used was a Norelco X-ray diffractometer equipped with a Geiger counter and a Brown recorder. The radiation was CuK_{α} using a nickel filter. A tube potential of 35 kilovolts and a current of 15 milliamperes were used. The settings were $1/2^{\circ}$ - 0.006 - $1/2^{\circ}$ for the divergence, scatter, and receiving slits, respectively. A scale factor of 4 and a time constant of 8 were used on the recorder and the scanning time was 1 degree per minute. The scanning angle of $2\ \theta$ was 4 to 28 degrees which is equivalent to 22.07 Å to 3.18 Å.

The initial treatment for removing carbonates, soluble salts, and organic matter in the segregation of the clay fraction was carried out following the procedure of Jackson et al. (28). The dispersion of clays and the subsequent separation of the clay from the sand and silt followed by the separation of the clay into the fine and coarse fractions was carried out by a method used by Pawluk[1]. The clays were dispersed by adjusting the suspension to a pH of 8.0 using sodium hydroxide. After allowing the suspension to stand over night the pH was readjusted. The separation of the clay from the silt and sand fractions was done by decanting the solution above an 8 cm. depth from the top of the liquid following standing for 6 hours and 8 minutes.

[1] Personal communication.

The coarse (2 - 0.2 μ) and fine ($<$0.2 μ) clay fractions were separated by centrifugation of the clay suspension for 1 hour and 6 minutes at 1,800 r.p.m. Settling times and centrifuge speeds were calculated by the use of Stokes' Law adopted for centrifugation by Baver (11).

The clay fractions were flocculated with calcium by adding 25 ml. of saturated calcium chloride followed by washing with distilled water to remove chlorides. The clay suspensions were oriented on glass slides using a procedure similar to that outlined by Kittrick (30). The suspensions were allowed to dry by standing over night in petri dishes covered with a large ribbed cover glass. The ethylene glycol treatment of the air-dried mounted suspensions was carried out by placing prepared slides in a saturated atmosphere of ethylene glycol in a vacuum desiccator. The other treatment consisted of heating the sample to 550°C for 2 hours. The heat treated samples were stored in a desiccator.

The cation exchange capacities of the two clay fractions were determined following a procedure similar to that carried out for the exchange capacity of the whole soil except centrifugation was used to separate the suspension and solution.

RESULTS AND DISCUSSION

Field Trial Results

The average yields of the first and second harvests are shown in Table II. The low yields obtained at all locations were likely due to the extremely dry conditions that occurred in most parts of Alberta in 1961. Soil moisture conditions at time of fertilizer application were fair to very poor for the 0 - 12 inch depth and generally poor at the 12 - 36 inch depth. The low soil moisture content and the adverse distribution of precipitation during the season probably contributed to the poor response to fertilizer in 1961.

The yield responses to potassium applied at five levels were not significant with one exception, i.e. Jones, treatment 0-0-120. Potassium applied singly at the four rates depressed the yields for both first and second harvests on the Mauschmeyer farm. In this experiment certain combinations of nitrogen, phosphorus, and potassium also decreased yields. At the other sites there were some significant responses to applications of nitrogen and phosphorus.

Examination of the data show that none of the fertilizer applications were economical when based on the following: nitrogen, phosphorus, and potassium at 12, 9, and 5 cents per pound, respectively, and hay at 20 dollars per ton. Alfalfa, being a deep rooted crop, probably responds rather sluggishly to the application of fertilizer. This together

TABLE II. ALFALFA YIELDS FROM FIRST AND SECOND CUTS AT TEN SITES (tons per acre, average of six replicates).

	Church		Jones		Boyack		Maga		Atkinson		Wiesener		Ripple		Adam		Mauschmeyer		Holmlund	
	Cuts		Cuts		Cuts		Cuts		Cuts		Cuts		Cuts		Cuts		Cuts		Cuts	
Treatment	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
0-0-0	0.75	0.72	0.50	0.58	0.92	0.48	1.43	0.95	0.68	0.30	0.84	0.62	0.50	0.59	0.95	0.72	1.36	1.79	0.91	0.32
0-0-30	0.86	0.80	0.50	0.55	0.80	0.46	1.49	0.98	0.66	0.34	0.88	0.60	0.56	0.70	1.06	0.79	1.10*	1.41*	0.86	0.38
0-0-60	0.84	0.78	0.59	0.57	0.90	0.50	1.35	0.80	0.73	0.35	0.84	0.63	0.52	0.55	1.10	0.83	1.12*	1.32*	0.90	0.35
0-0-90	0.77	0.73	0.58	0.61	0.71	0.47	1.41	0.76	0.65	0.33	0.83	0.65	0.53	0.64	1.07	0.76	0.99*	1.21*	0.72	0.34
0-0-120	0.74	0.72	0.68*	0.66	0.81	0.44	1.43	0.87	0.80	0.29	0.88	0.66	0.59	0.68	1.05	0.79	1.12*	1.40*	0.79	0.34
20-40-0	0.95*	0.92*	0.57	0.62	0.86	0.52	1.67	0.97	0.97*	0.60*	0.85	0.60	0.54	0.85*	1.13	0.91*	1.19	1.54*	0.80	0.34
20-40-30	0.95*	0.84*	0.52	0.60	0.80	0.53	1.64	1.08	0.92*	0.56*	0.88	0.63	0.54	0.83*	0.98	0.89*	1.35	1.65	0.93	0.36
20-40-60	0.94*	0.82*	0.62	0.70*	0.98	0.46	1.52	1.07	0.93*	0.60*	0.92	0.63	0.53	0.77*	1.00	0.85*	1.14*	1.47*	0.88	0.34
20-40-90	1.07*	0.90*	0.54	0.63	0.89	0.54	1.62	1.01	0.95*	0.60*	0.83	0.59	0.54	0.87*	0.99	0.90*	1.22	1.56*	0.95	0.33
20-40-120	0.94*	0.81	0.47	0.64	0.81	0.52	1.77*	1.14	0.92*	0.61*	0.83	0.64	0.59	0.89*	1.10	0.92*	1.15*	1.57*	0.85	0.35
40-80-0	0.92*	0.93*	0.50	0.67	0.89	0.55	1.72*	1.18*	1.04*	0.74*	0.92	0.63	0.65*	0.95*	1.07	0.93*	1.08*	1.64	0.85	0.40*
40-80-30	1.02*	0.94*	0.65*	0.71*	0.97	0.59*	1.64	1.16*	1.10*	0.81*	0.75	0.66	0.64	1.05*	0.95	0.94*	1.26	1.72	0.98	0.37
40-80-60	1.12*	1.00*	0.59	0.68*	0.89	0.51	1.73*	1.17*	1.04*	0.78*	0.89	0.66	0.59	1.00*	1.21*	1.01*	1.41	1.53*	0.91	0.39
40-80-90	1.04*	0.94*	0.56	0.63	0.98	0.52	1.97*	1.31*	1.13*	0.74*	0.86	0.65	0.49	1.01*	1.01	1.00*	1.22	1.70	0.91	0.40*
40-80-120	1.01*	0.96*	0.66*	0.72*	0.85	0.50	1.81*	1.23*	1.09*	0.77*	0.84	0.65	0.56	0.95*	1.08	0.93*	1.22	1.62	0.92	0.36
L.S.D.	0.14	0.10	0.15	0.10	0.23	0.08	0.25	0.21	0.16	0.13	0.12	0.08	0.15	0.17	0.21	0.12	0.18	0.22	0.20	0.08

* Significance at 0.05 level.

with poor moisture conditions during the summer of 1961 emphasizes that the yield data in Table II may not be very meaningful. For these reasons some of the field experiments should be continued in order to evaluate the responses over a period of about three years.

Soil Analyses

A number of chemical and physical analyses were performed in order to characterize the soils used in this study. The results of these analyses appear in Table III. The mechanical analyses indicate that the glacial tills on which the soils were developed were loam to clay loam in texture with the clay content varying from 17 to 32 per cent. The texture of the Aa horizon of most profiles was loam with the clay content ranging from 13 to 29 per cent. There were two exceptions, however, the texture of the Ponoka series Aa horizon was fine sandy clay loam and the texture of the Aa horizon of the Airdrie series on the Jones farm was clay loam.

The organic matter content of the Aa horizons of the Airdrie series ranged from 4.4 to 8.6 per cent, for the Angus Ridge series from 7.0 to 9.6 per cent, the Falun series from 5.0 to 5.8 per cent, and the Uncas series from 2.6 to 3.2 per cent (Table III). The organic matter content increased to a maximum under grassland vegetation from an area of relatively low to that of relatively high moisture efficiency but decreased again in soils developed under deciduous forest vegetation.

TABLE III. SOME CHEMICAL AND PHYSICAL ANALYSES OF SOILS FROM THE TWELVE SITES.

Soil Type	Horizon	Depth in.	Mechanical Analysis %S	%Si	%C	% 0.2 µC	% Organic Matter	Exchange Capacity (m.e./100 gm. air dry soil)	Exchangeable Ca^{++}	Exchangeable Mg^{++}	pH
Airdrie L (Church)	Aa	6	35	42	23	11	6.8	30.0	23.5	4.4	6.6
	Ah	1	27	45	28	13	4.4	29.2	18.6	5.2	6.6
	Bm_1	3	28	45	27	15	-	22.6	23.3	5.1	7.0
	Bm_2	5	40	36	24	13	-	19.3	13.8	5.0	6.9
	C	@15	42	41	17	8	-	12.6	32.8	4.2	7.8
Airdrie CL (Jones)	Aa	6	39	32	29	10	8.6	33.2	22.1	4.4	6.3
	Ah	2	39	37	24	12	5.8	27.7	34.4	3.5	6.7
	Bm_1	5	38	36	24	13	-	18.0	25.2	3.5	6.7
	Bm_2	3	29	52	19	13	-	19.8	18.8	4.1	6.6
	C	@16	37	37	26	8	-	13.6	33.1	4.4	7.7
Airdrie L (Boyack)	Aa	6	40	47	13	6	4.4	16.8	12.5	2.8	6.2
	Ah	2	58	26	16	6	3.4	17.9	12.7	3.1	6.1
	AB	1	-	-	-	-	-	14.1	9.8	2.9	-
	Bm_1	7	62	23	15	5	-	12.8	9.1	2.6	6.3
	Bm_2	8	60	24	16	5	-	12.2	9.1	2.9	6.4
	C	@24	50	31	19	4	-	12.4	32.0	4.0	7.7
Cygnet L (Maga)	Aa	6	30	47	26	13	8.8	39.6	32.3	6.2	6.4
	Ah	6	27	47	29	14	4.0	29.2	21.7	5.5	6.3
	AB	2	26	44	30	25	-	23.6	17.7	5.7	6.1
	Bm_1	9	40	30	30	12	-	22.3	17.0	3.2	6.3
	Bm_2	7	33	36	31	10	-	24.4	20.5	5.8	6.7
	C	@30	30	40	30	8	-	20.7	34.3	7.1	7.6
Ponoka FSCL (Atkinson)	Aa	6	50	23	27	12	9.8	40.0	45.7	10.8	7.3
	Ah	9	50	24	26	9	5.0	27.9	44.9	12.7	7.7
	AB	2	53	22	25	9	-	21.3	35.6	10.1	7.7
	Bm_1	10	63	15	22	11	-	16.3	19.9	7.4	7.8
	Bm_2	8	70	10	20	8	-	15.6	25.1	6.3	7.7
	C	@35	58	23	19	10	-	14.2	38.2	6.5	7.8
Angus Ridge L (Wiesener)	Aa	6	33	41	26	16	7.0	34.8	28.7	5.3	6.4
	Ah	7	35	40	25	17	4.6	26.9	22.3	5.5	6.6
	AB	1	33	40	27	18	-	21.0	15.8	5.6	6.7
	Btj	16	39	32	29	22	-	22.3	16.0	7.3	6.9
	Bm	8	44	31	25	16	-	20.2	15.2	6.8	7.1
	C	@38	45	32	23	16	-	18.8	27.5	6.6	7.5

TABLE III. (Continued)

Soil Type	Horizon	Depth in.	Mechanical Analysis %S	%Si	%C	% 0.2 μC	% Organic Matter	Exchange Capacity (m.e./100 gm.	Exchangeable Ca^{++} air dry soil)	Exchangeable Mg^{++}	pH
Angus Ridge L (Ripple)	Aa	6	42	34	24	9	8.0	32.5	24.4	5.7	6.2
	Ah	8	40	36	24	11	5.0	23.3	16.3	5.7	6.4
	AB	1	-	-	-	-	-	11.5	7.3	3.5	-
	Btj	12	43	28	29	18	-	21.0	13.2	6.9	6.4
	Bm	8	43	27	30	16	-	19.9	15.3	6.7	7.0
	C	@36	43	31	26	11	-	15.7	32.3	5.9	7.6
Angus Ridge L (Adam)	Aa	6	37	36	27	12	9.6	37.3	28.6	5.8	6.2
	Ah	7	37	39	24	11	6.6	31.8	22.7	6.2	6.1
	AB	1	43	33	24	14	-	18.4	10.7	6.1	5.7
	Bt	12	41	25	34	18	-	21.7	12.8	7.0	5.6
	Btj	10	45	26	29	16	-	19.7	13.4	6.8	6.3
	C	@36	44	31	25	12	-	18.2	20.3	7.1	7.2
Falun L (Mauschmeyer)	Aa	6	47	34	19	9	5.0	23.8	21.5	3.1	6.6
	Ah	6	43	38	19	6	3.2	20.8	18.2	3.0	6.8
	Ahe	3	36	43	21	13	-	15.9	12.6	3.8	6.7
	Bt	15	51	27	22	18	-	18.5	16.3	2.4	6.3
	Bm	12	47	36	17	14	-	17.1	16.3	1.9	6.6
	C	@42	50	26	24	13	-	14.9	17.3	4.4	7.2
Falun L (Holmlund)	Aa	6	39	43	18	7	5.8	31.3	21.7	3.6	6.4
	Ah	2	42	38	20	9	4.0	27.7	17.2	3.5	6.0
	Ahe	2	41	36	23	12	-	18.6	12.9	3.6	5.9
	Bt	20	43	30	27	14	-	21.4	15.4	4.4	5.7
	Btj	12	47	27	26	12	-	20.9	15.8	4.7	5.8
	C	@32	46	31	23	9	-	18.8	24.4	4.8	6.9
Uncas L (Hughes)	Aa	6	42	38	20	7	3.2	15.6	11.4	2.9	6.3
	Ae	1	39	30	31	17	-	15.9	8.6	4.7	5.7
	Bt	14	39	30	37	23	-	22.3	16.3	4.5	5.2
	Bm	15	39	24	32	19	-	19.3	13.2	7.7	6.4
	C	@36	37	31	32	17	-	17.7	33.0	7.8	7.5
Uncas L (Williams)	Aa	6	49	39	12	5	2.6	11.8	10.5	1.8	6.7
	Bt	18	40	27	33	20	-	18.4	13.4	3.3	5.8
	Btj	14	41	28	31	19	-	18.6	13.0	4.6	5.9
	C	@38	40	33	27	15	-	16.7	21.8	2.3	7.1

The cation exchange capacity of the surface horizons varied from a low of 11.8 m.e. per 100 grams to a high of 40. The low values of 11.8, 15.6, and 16.8 were in the two Uncas series profiles and one Airdrie series (Boyack), respectively. The organic matter and clay contents of these were low in comparison with other profiles and would account for the low cation exchange capacity. The reaction of the surface soils indicate that all were slightly acid with pH values of 6.2 to 6.6 with the exception of the Ponoka series which was slightly alkaline (pH 7.3). In the latter profile, the presence of free lime was noted in all horizons at time of sampling. It is for this reason that the calcium values exceeded the cation exchange capacity (Table III).

The potassium extractable with 1 N NH_4Ac, 0.025 N HAc, and boiling 1 N HNO_3 are shown in Table IV. The data show that the potassium extracted by 1 N NH_4Ac from the surface horizon of the Airdrie series is greater than in the Angus Ridge, Falun, and Uncas series. The values for the Airdrie series were 1.1, 1.0, and 0.8; for the Angus Ridge series 0.4, 0.4, and 0.4; for the Falun series 0.7 and 0.5; and for the Uncas series 0.5 and 0.5 m.e. per 100 grams of air dry soil. The per cent potassium saturation of the Aa horizons of the Airdrie soils is higher than that of the Angus Ridge (Table IV). It is noted that the potassium saturation decreases with depth in the Airdrie series whereas it generally increases with depth in the Angus Ridge series. Halstead _et al_. (22) found that exchangeable potassium (NH_4Ac) in 4 of 6 soils analyzed at depths of 0 to 7 inches, 7 to 14 inches, and 14 to 21 inches

TABLE IV. POTASSIUM EXTRACTED WITH 1 N NH_4Ac, 0.025 N HAc, AND BOILING 1 N HNO_3.

Soil Type	Horizon	NH_4Ac	%K Sat.	HAc	Boiling 1 N HNO_3
		(m.e. / 100 gm. air dry soil)			
Airdrie L (Church)	Aa	1.1	3.7	0.25	3.3
	Ah	0.8	2.7	0.13	4.3
	Bm_1	0.6	2.7	0.13	3.4
	Bm_2	0.5	2.6	0.11	2.4
	C	0.3	2.4	0.13	1.5
Airdrie CL (Jones)	Aa	1.0	3.0	0.24	3.2
	Ah	0.4	1.4	0.11	2.6
	Bm_1	0.5	2.8	0.14	2.6
	Bm_2	0.5	2.5	0.14	2.3
	C	0.3	2.2	0.13	1.6
Airdrie L (Boyack)	Aa	0.8	5.3	0.28	3.2
	Ah	0.4	2.8	0.11	2.6
	AB	0.3	2.1	-	-
	Bm_1	0.4	3.3	0.08	2.1
	Bm_2	0.3	2.5	0.09	1.7
	C	0.2	2.4	0.10	1.1
Cygnet L (Maga)	Aa	0.6	1.5	0.10	2.5
	Ah	0.4	1.4	0.07	2.0
	AB	0.4	1.7	0.09	2.0
	Bm_1	0.4	1.8	0.09	1.7
	Bm_2	0.4	1.6	0.08	1.4
	C	0.3	1.4	0.10	1.5
Ponoka FSCL (Atkinson)	Aa	0.4	1.0	0.06	1.6
	Ah	0.3	1.1	0.05	1.6
	AB	0.1	1.4	0.06	1.7
	Bm_1	0.3	1.8	0.08	1.6
	Bm_2	0.3	1.9	0.08	1.5
	C	0.2	1.4	0.08	1.5
Angus Ridge L (Wiesener)	Aa	0.4	1.1	0.07	1.6
	Ah	0.4	1.5	0.07	1.6
	AB	0.4	1.9	0.07	1.6
	$B\overline{tj}$	0.4	1.8	0.08	1.5
	Bm	0.4	2.0	0.08	1.2
	C	0.4	2.1	0.10	1.2

TABLE IV. (Continued)

Soil Type	Horizon	(m. e. / 100 gm. air dry soil) NH_4Ac	%K Sat.	HAc	Boiling 1 N HNO_3
Angus Ridge L (Ripple)	Aa	0.5	1.5	0.12	1.9
	Ah	0.3	1.3	0.07	1.5
	AB	0.2	1.7	0.06	1.0
	B$\overline{tj}$	0.4	1.9	0.08	1.7
	Bm	0.3	1.6	0.09	1.6
	C	0.3	1.9	0.14	1.6
Angus Ridge L (Adam)	Aa	0.4	1.1	0.09	1.7
	Ah	0.3	0.9	0.08	1.6
	AB	0.3	1.6	0.09	1.5
	Bt	0.4	1.8	0.10	1.6
	B$\overline{tj}$	0.4	2.0	0.10	1.6
	C	0.4	2.2	0.12	1.5
Falun L (Mauschmeyer)	Aa	0.7	2.9	0.18	2.4
	Ah	0.6	2.9	0.11	1.9
	Ahe	0.5	3.1	0.11	1.8
	Bt	0.7	3.8	0.09	1.5
	Bm	0.4	2.3	0.10	1.5
	C	0.3	2.0	0.10	1.6
Falun L (Holmlund)	Aa	0.5	1.6	0.08	1.7
	Ah	0.3	1.1	0.06	1.6
	Ae	0.3	1.6	0.07	1.6
	Bt	0.3	1.4	0.09	1.5
	B$\overline{tj}$	0.3	1.4	0.08	1.4
	C	0.3	1.6	0.10	1.1
Uncas L (Hughes)	Aa	0.5	3.2	0.11	1.7
	Ae	0.4	2.5	0.09	1.7
	Bt	0.5	2.2	0.11	1.9
	Bm	0.5	2.6	0.08	1.6
	C	0.5	2.8	0.12	1.8
Uncas L (Williams)	Aa	0.5	4.2	0.11	1.6
	Bt	0.6	3.3	0.11	2.3
	B$\overline{tj}$	0.5	2.7	0.10	2.0
	C	0.5	3.0	0.11	1.9

did not vary appreciably between the surface and subsurface samples. However, the per cent potassium saturation increased with depth in these soils. Results of a greenhouse experiment with these soils taken at the three depths did not indicate a pronounced difference between the potassium-supplying powers of corresponding surface and subsurface samples. Wells and Parks (63), however, found available potassium (extracted with 0.05 N H_2SO_4 plus 1 per cent $(NH_4)_2SO_4$) to be highest in the 0 to 1-inch layer and generally decreased from the surface downward through the profile. These results were obtained when soils were analyzed from plots receiving no annual applications of potassium during the 6-year study. They found in the four soils studied that the amount of potassium in the 0 to 1-inch level was double that of the 1 to 3-inch and subsequent depths. The texture of the soils ranged from silt loam to silty clay loam. Where annual applications of potassium were added they found that the rate of potassium movement through medium to fine textured soil profiles was not as rapid as some workers have suggested.

The HAc method extracted considerably less potassium from the surface horizon than the NH_4Ac method. However, the same trends are noted for both methods when all soils are compared. The data are depicted in Figure 2 where there appears to be a greater relative difference between the various amounts of potassium extracted by the HAc method than by the NH_4Ac method.

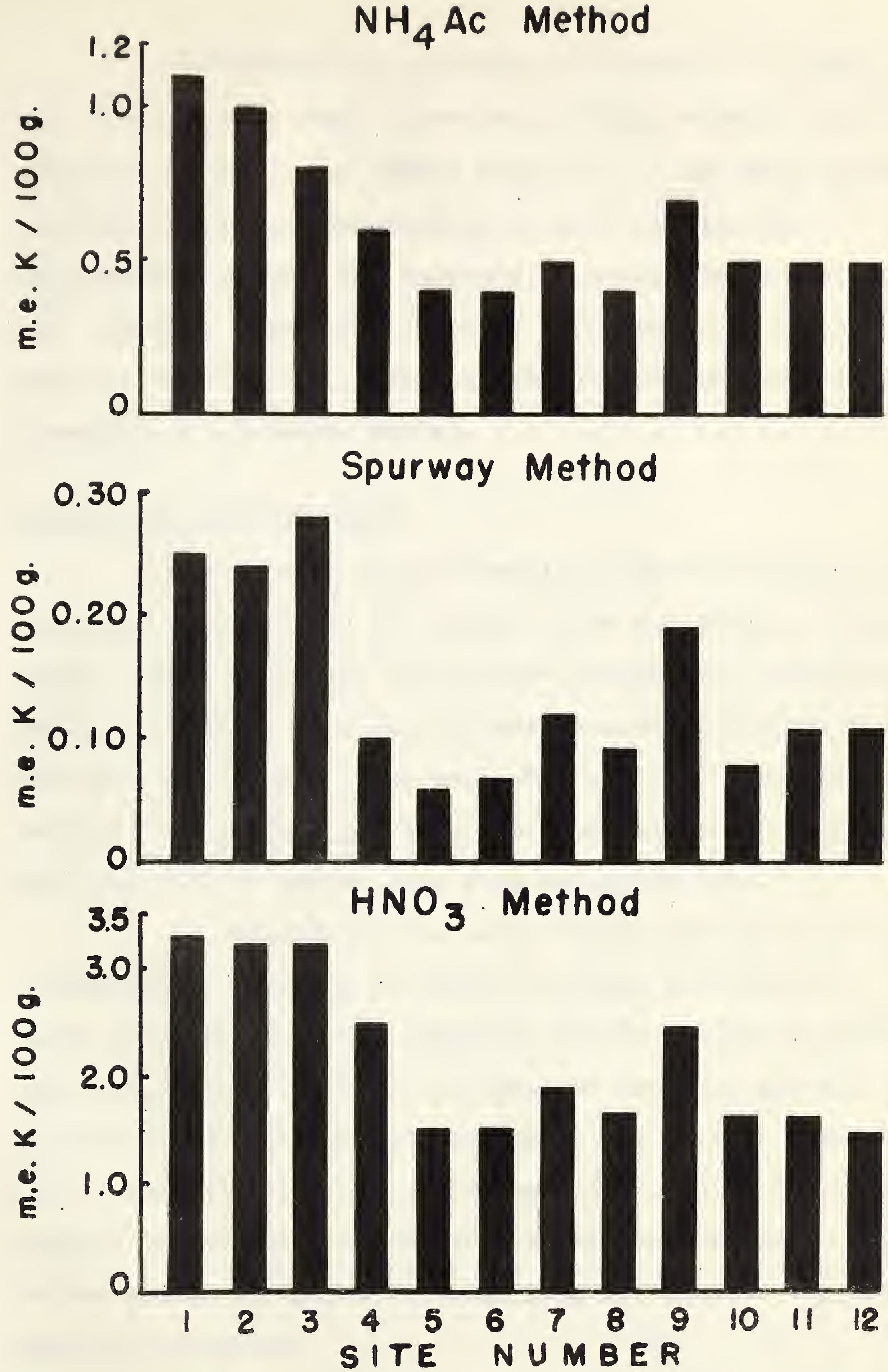

Figure 2. The quantities of potassium extracted by 1 N NH_4Ac, 0.025 N HAc (Spurway), and boiling 1 N HNO_3 from the Aa horizon of profiles from twelve sites.

The amounts of potassium extracted by 1 N HNO_3 were much greater than those extracted by NH_4Ac because the former treatment is much more severe (Figure 2). The HNO_3 extracted potassium includes exchangeable as well as some non-exchangeable forms. The quantity of potassium extracted with the HNO_3 treatment generally decreases with depth. However, it is noted that there is an increase in the illuviated B horizon of the Uncas series.

Repeated Acid Extractions

The surface horizon samples from all profiles and the major horizons for one profile from the Airdrie, Angus Ridge, Falun, and Uncas series were repeatedly extracted with boiling 1 N HNO_3. The results are presented in Table V and are depicted in Figure 3. The data show that the first and subsequent extractions removed greater quantities of potassium from the Airdrie series than from any other soil.

An estimate of the more soluble portion of the non-exchangeable potassium is given in column 8 of Table V. This value is computed by the summation of the amounts of potassium removed in the first three extractions less the sum that was removed by extractions four and two times that of extraction five. This was also done by MacLean (37) and is fairly comparable to the "Step K" referred to by Haylock (23). These values appear to follow the same general trend as the other forms of potassium.

It is also noted that the potassium released decreases with depth as shown in Figures 4a and 4b. There is an exception,

TABLE V. POTASSIUM EXTRACTED BY EXTRACTION WITH 0.1 N HNO_3 FOLLOWED BY REPEATED EXTRACTIONS WITH 1 N HNO_3 (m.e. / 100 gm. air dry soil).

Soil Type	Horizon	K Removed Initially with 0.1 N HNO_3	Repeated Extractions with 1 N HNO_3					Estimates of More Soluble Non-exch. K*
			1	2	3	4	5	
Airdrie L (Church)	Aa	1.2	2 6	1.4	0.9	0.8	0.6	2.9
	Ah	0.7	2.6	1.7	1.2	0.9	0.7	3.2
Airdrie CL (Jones)	Aa	1.0	2.5	1.1	0.8	0.6	0.6	2.6
	Ah	0.5	2.2	0.9	0.7	0.6	0.5	2.2
	Bm_1	0.4	2.2	1.0	0.7	0 6	0.5	2.3
	Bm_2	0.4	2.0	0.9	0.6	0.6	0.5	1.9
	C	0.3	1.4	0.7	0.5	0.4	0.4	1.4
Airdrie L (Boyack)	Aa	0.7	2.2	0.8	0.6	0.5	0.4	2.3
	Ah	0.5	2.2	1.0	0.7	0.5	0.5	2.4
Cygnet L (Maga)	Aa	0.5	1.8	0.8	0.6	0.4	0.4	2.0
Ponoka FSCL (Atkinson)	Aa	0.3	1.0	0.5	0.4	0.3	0.3	1.0
Angus Ridge L (Wiesener)	Aa	0.3	1.3	0.5	0.4	0.4	0.4	1.0
Angus Ridge L (Ripple)	Aa	0.4	1.5	0.7	0.4	0.4	0.4	1.4
	Ah	0.2	1.4	0.6	0.4	0.4	0.4	1.2
	$B\overline{tj}$	0.3	1.5	0.6	0.4	0.4	0.4	1.3
	Bm	0.3	1.4	0.6	0.4	0.4	0.3	1.4
	C	0.2	1.5	0.6	0.4	0.2	0.2	1.9
Angus Ridge L (Adam)	Aa	0.3	1.7	0.8	0.4	0.4	0.2	1.7
Falun L (Mauschmeyer)	Aa	0.7	1.6	0.6	0.5	0.3	0.2	2.0
	Ah	0.4	1.3	0.7	0.4	0.2	0.3	1.6
	Ahe	0.4	1.5	0.6	0.5	0.2	0.3	1.8
	Bt	0.4	1.1	0.5	0.4	0.2	0.2	1.4
	Bm	0.3	1.1	0.5	0.4	0.2	0.2	1.4
	C	0.3	1.1	0.4	0.4	0.3	0.3	1.0
Falun L (Holmlund)	Aa	0.4	1.4	0.5	0.4	0.4	0.4	1.1
Uncas L (Hughes)	Aa	0.4	1.4	0.5	0.4	0.4	0.4	1.1
Uncas L (Williams)	Aa	0.4	1.4	0.5	0.4	0.4	0.4	1.1
	Bt	0.4	2.1	0.7	0.5	0.5	0.4	2.0
	$B\overline{tj}$	0.3	1.8	0.7	0.5	0.5	0.4	1.7
	C	0.4	1.9	0.6	0.4	0.4	0.4	1.7

* Estimates calculated for the more soluble non-exchangeable potassium released by summation of extractions 1, 2, and 3 minus amounts released by extractions 4 and twice 5.

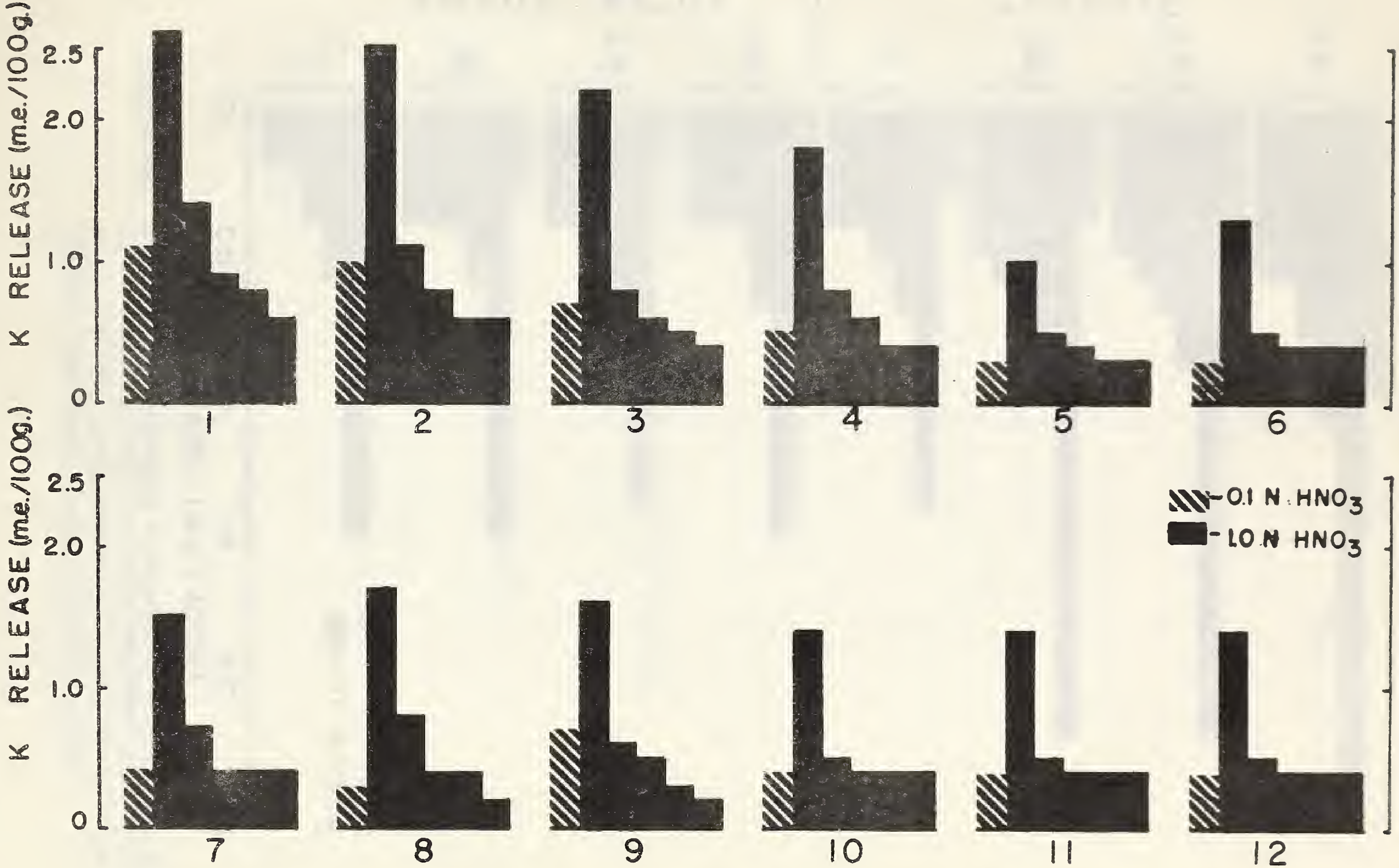

Figure 3. Amounts of potassium released by extraction with 0.1 N HNO_3 followed by five repeated extractions with 1 N HNO_3 from the Aa horizon of profiles from twelve sites.

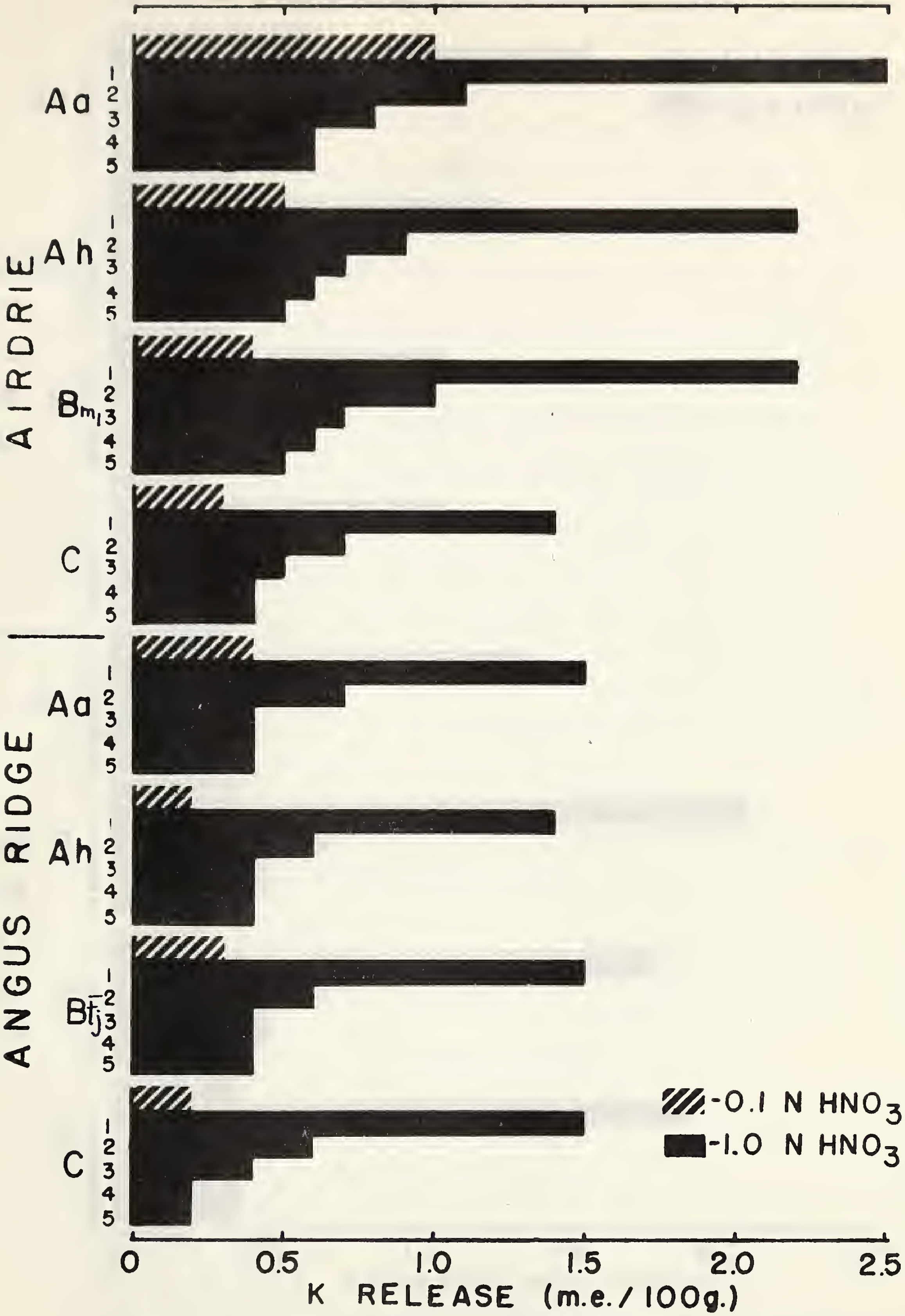

Figure 4a. Amounts of potassium released by extraction with 0.1 N HNO_3 followed by five repeated extractions with 1 N HNO_3 from the major horizons of Airdrie (Jones) and Angus Ridge (Ripple) soils.

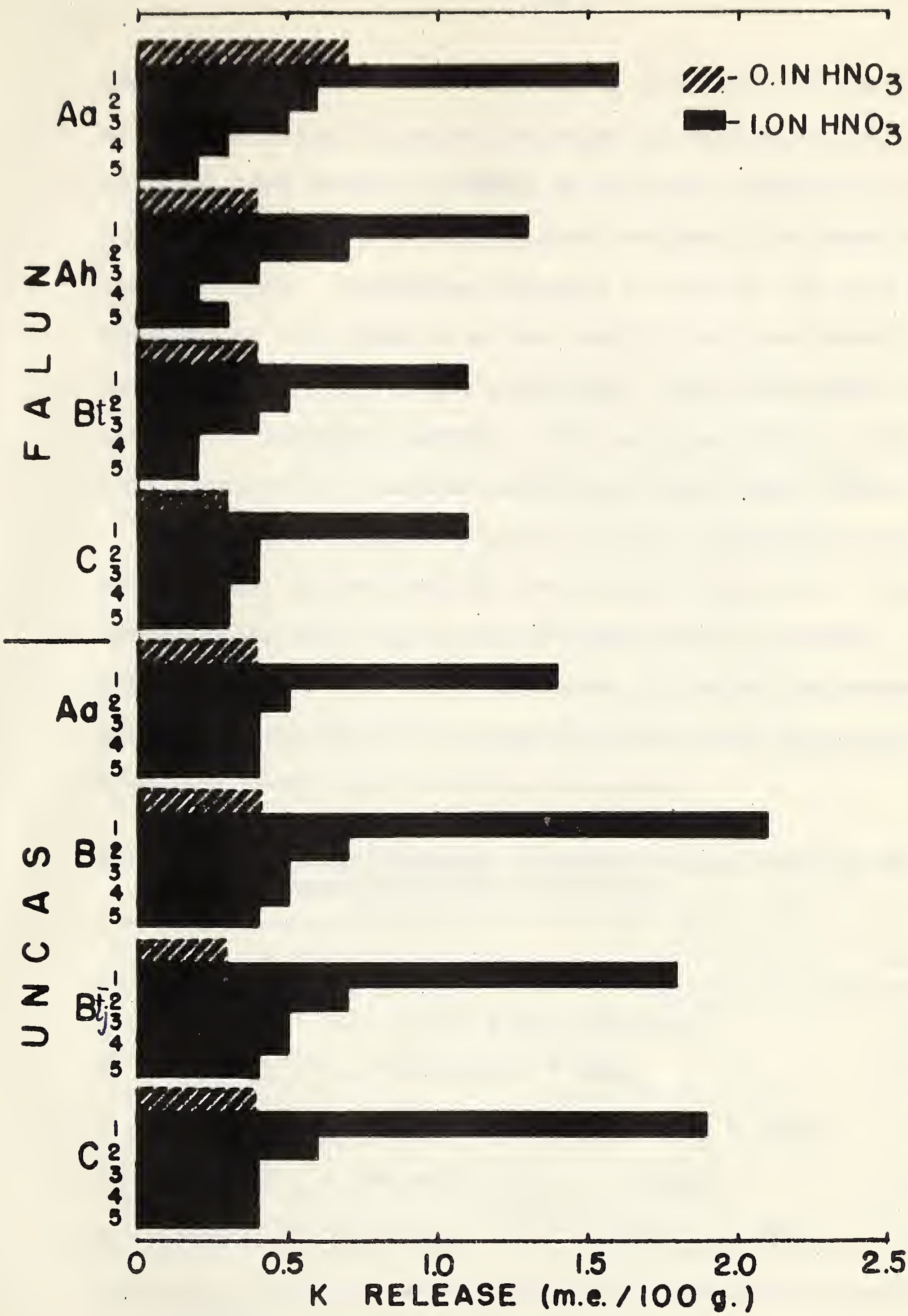

Figure 4b. Amounts of potassium released by extraction with 0.1 N HNO_3 followed by five repeated extractions with 1 N HNO_3 from the major horizons of the Falun (Mauschmeyer) and Uncas (Williams) soils.

however; the subsurface horizons of the Uncas released more potassium in the first two repeated extractions than the Aa horizon. The amount released by this soil during the third, fourth, and the fifth extractions was about the same for the four horizons. Potassium released by the Aa, Ah, and Bm_1 horizons of the Airdrie series profile was considerably greater than that released by the C horizon. The values for the C horizon of Airdrie, however, were not appreciably different from those of the various horizons of the Angus Ridge.

Correlations between the soil potassium values obtained by various methods are given in Table VI. These correlations were highly significant for all methods. It is interesting to note that the amount of potassium removed by the 0.1 N HNO_3 prior to repeated extractions correlated very highly (0.932) with 1 N NH_4Ac potassium.

TABLE VI. THE RELATIONSHIP BETWEEN VARIOUS METHODS FOR DETERMINING SOIL POTASSIUM.

Methods	r-value
1. 1 N NH_4Ac vs. 0.025 N HAc (Spurway)	0.782**
2. 1 N NH_4Ac vs. Boiling 1 N HNO_3	0.775**
3. More soluble non-exchangeable vs. 1 N NH_4Ac	0.709**
4. 0.1 N HNO_3 extractable vs. 1 N NH_4Ac	0.932**
5. 0.025 N HAc (Spurway) vs. Boiling 1 N HNO_3	0.665**

** Significance at the 0.01 level.

Plant Analyses

Alfalfa samples from each of the six replicates of the check and 0-0-120 treatments from four locations were analyzed for potassium content. The results are presented in Table VII.

TABLE VII. POTASSIUM CONTENT OF ALFALFA PLANTS (per cent of oven dry weight, average of six replicates).

Soil Series	Treatment 0-0-0	Treatment 0-0-120
Airdrie		
(Church)	4.2	4.1
(Jones)	3.7	3.8
Angus Ridge		
(Weisener)	2.5	2.4
(Ripple)	2.4	2.5

An analysis of variance indicated a highly significant difference between the potassium content of plants from the two soil series. The fertilizer treatment had no effect on the potassium content of the plants. It would appear that due to the light rainfall the added potassium may not have been made available for plant growth. Another possibility is the added potassium was fixed in the soil. In any case, it is obvious that the experiments should be continued in order to study the effects over at least a 3-year period. The high potassium content of the Airdrie series appears to have favored luxury consumption by the

plants (11). According to Morrison (41), the potassium content of alfalfa hay ranges from 1.97 to 2.14 per cent depending upon physiological stage at which the plant is sampled.

Mineralogical Analysis

The results of X-ray diffraction analysis of the clay fractions of the major soil horizons of the Airdrie, Angus Ridge, Falun, and Uncas series are presented in Table VIII.

The data show that all soils contained montmorillonite, illite, kaolinite, and chlorite. As expected, there was generally more montmorillonite in the fine clay fraction than in the coarse fraction (19). Also, as anticipated, more illite, kaolinite, and chlorite were present in the coarse fraction than in the fine fraction. The intensity of one clay mineral, however, should not be compared with the intensity of another. It is realized that more analytical studies would have to be performed in order to determine semi-quantitatively the clay mineral content. Pawluk[1] has confirmed this by comparing peak intensities for a mixture of equal portions of pure montmorillonite, kaolinite, and illite. However, using the intensities of the foregoing standard clays as background information together with the cation exchange capacities of the two size fractions (Table VIII)

[1] Personal communication.

TABLE VIII. CLAY MINERAL DISTRIBUTION IN SOME SOILS USED IN THIS STUDY.

Soil Type	Horizon	Montmorillonite 2-0.2 microns	Montmorillonite <0.2 microns	Illite 2-0.2 microns	Illite <0.2 microns	Kaolinite 2-0.2 microns	Kaolinite <0.2 microns	Quartz 2-0.2 microns	Quartz <0.2 microns	Chlorite 2-0.2 microns	Chlorite <0.2 microns	C.E.C.* 2-0.2 microns	C.E.C.* <0.2 microns
Airdrie CL (Jones)	Aa	3**	58**	8**	8**	7**	5**	14**	8**	0**	0**	23.6	45.3
	Ah	15	74	11	6	8	4	15	8	2	0	21.0	44.1
	Bm_1	49	104	16	2	16	8	30	8	5	0	27.7	44.9
	C	74	120	17	4	23	6	30	4	12	0	39.4	49.3
Angus Ridge L (Ripple)	Aa	0	112	6	4	8	6	25	4	4	0	23.0	51.7
	Bt	74	144	10	0	23	6	37	4	5	0	29.7	50.3
	C	46	160	9	4	12	7	21	6	2	0	36.7	46.9
Falun L (Mauschmeyer)	Aa	16	23	6	2	6	2	24	3	0	0	27.5	62.5
	Bt	47	51	7	2	12	1	22	5	2	0	36.2	58.9
	C	53	21	8	1	10	1	27	3	2	0	32.8	43.0
Uncas L (Williams)	Aa	11	26	8	2	9	2	32	3	2	0	-	42.0
	Bt	32	116	7	4	12	4	34	12	2	0	23.8	46.5
	C	66	45	9	6	18	4	33	16	4	0	29.7	60.0

* m.e. per 100 gm.

** Expressed as units above background converted to a standard intensity setting of 4 - 1 - 8.

plus information published elsewhere (19, 45) it would appear that montmorillonite and illite are the predominant clay minerals. It should be noted, however, that this was not the main objective for doing X-ray diffraction analysis. The main reason was to determine the relative amounts of the 10 to 11 Å minerals in the various soils in order to learn whether this aspect had an important bearing on the potassium status of these soils.

The intensities of the 10 to 11 Å peaks for the various soils suggest that the Airdrie soil contains a greater quantity of these clay minerals than the other soils. This is particularly noticeable in the coarse fractions of the B and C horizons and the fine fractions of the Aa and Ah horizons. This is considered to be important because it at least partially explains the higher potassium content of the Airdrie soils as compared to the others.

The soils used in the present study represent those which have developed under different climatic conditions and the results suggest that the various forms of potassium are a result of differences in the degree of weathering. It is felt there is justification for this statement because texture, which could also affect the potassium status, was fairly comparable for all soils (Table III).

It is suggested that the Airdrie has undergone less weathering and consequently less leaching than the other soils, thereby soluble and exchangeable forms have not been lost as readily through leaching. Reitemeier _et al_. (49) reported

considerable differences in potassium values between a soil in "Stage I" of development and one in "Stage III". Stage of development appears to refer to the degree of weathering, i.e., "Stage I" soils show the least weathering. The values for exchangeable potassium were 400 and 180 pounds per acre for "Stage I" and "Stage III", respectively. The values released by boiling nitric acid were 980 and 520 pounds per acre, respectively. Reitemeier et al. (50) stated that relatively unweathered mineral soils of areas of deficient rainfall usually do not require potassium fertilizer. Soils of these regions usually contain large quantities of potassium much of which is present in the unweathered primary minerals. In a study of soils from the northern Great Plains, these workers obtained exchangeable potassium (ammonium acetate extractable) values of 1,300 to 1,680 pounds per acre or equivalent to 1.7 to 2.1 m.e. per 100 grams. They considered these values as being extremely high. These values are much higher than the exchangeable values obtained for the Airdrie soil. Reitemeier et al. (50) stated that "the period of time that any soil will continue to supply sufficient potash for maximum crop production will depend greatly on the quantity removed from the field in harvested crops". This statement may have considerable merit in that the Airdrie soils may be supplying crops with quantities of potassium in excess of amounts required for crop production and thus, the reserves indicated by soil tests may be gradually lowered to those more comparable to the other soils in this study.

SUMMARY AND CONCLUSIONS

During the period 1959 to 1961 approximately 3,000 soil samples have been analyzed in the Agricultural Soil and Feed Testing Laboratory. The potassium values were plotted on a map and it was noted that the soils in the Brown, Dark Brown, and Thin Black soil zones generally had considerably higher potassium contents than those in the Black, Transition, and Grey Wooded zones. The present study was organized to study several aspects of this observation. Experimental sites were located on the Airdrie, Angus Ridge, Falun, and Uncas series which are situated in the Thin Black, Black, Transition, and Grey Wooded zones, respectively. These sites were located on soils of similar texture, parent material, and drainage because it is known that these factors will affect the potassium content of soils. Also, all sites were being cropped to alfalfa.

The following is a summary of the results:

(i) Potassium extracted by 1 N NH_4Ac from the surface 0 to 6-inch depth averaged 1.0, 0.4, 0.6, and 0.5 m.e. per 100 grams for the Airdrie, Angus Ridge, Falun, and Uncas series, respectively, which indicates that the Airdrie series has approximately twice the potassium content as other soils. Quantities of potassium extracted with 0.025 N HAc were 0.26, 0.09, 0.13, and 0.11 m.e. per 100 grams for the Airdrie, Angus Ridge, Falun, and Uncas soil series, respectively. Acid extractable potassium as determined by

the boiling 1 N HNO_3 method gave 3.2, 1.7, 2.0, and 1.6 m.e. per 100 grams, respectively, for the above soils.

(ii) The rate of release of potassium using a repeated boiling 1 N HNO_3 extraction showed that the Airdrie soils released greater quantities of potassium than the other soils during each of five repeated extractions from the major horizons of the solum. The parent materials of all soils released similar quantities of potassium and at a similar rate. A measure of the more soluble portion of the repeated acid extractable potassium showed that release was 2.6, 1.2, 1.6, and 1.1 m.e. per 100 grams for the Airdrie, Angus Ridge, Falun, and Uncas series, respectively.

(iii) Although 1 N HNO_3 extracted from 2 to 3 times the amount of potassium and 0.025 N HAc extracted only 1/5 to 1/4 the amount extracted by 1 N NH_4Ac, these values significantly correlated with each other.

(iv) The Airdrie soil is characterized by a high quantity of potassium in the plow-depth in relation to the lower horizons and in comparison to the other soil series in this study.

(v) Mineralogical analyses indicate somewhat greater intensities of the 10 to 11 Å clay mineral peaks for all horizons of the Airdrie series as compared to the other series. This suggests the presence of greater quantities of these clay minerals in the Airdrie series than in the other series. It is also suggested that the former have undergone less weathering than the others.

It should be noted that better crystallization of the clay minerals can also account for at least some of the increased intensity of the peaks. The content of the 10 to 11 Å minerals may partially explain the higher potassium content of the Airdrie series as compared to the other soils.

(vi) Analyses of alfalfa grown on the Airdrie series compared to that grown on the Angus Ridge series show that the potassium contents were 3.9 and 2.5 per cent, respectively. The higher soil potassium content of the Airdrie appears to favor luxury consumption.

(vii) It is suggested that the Airdrie series has undergone less weathering and consequently less leaching than the other soils, thereby soluble, exchangeable, and acid extractable forms have not been lost as readily through leaching.

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